Single-phase Transformer

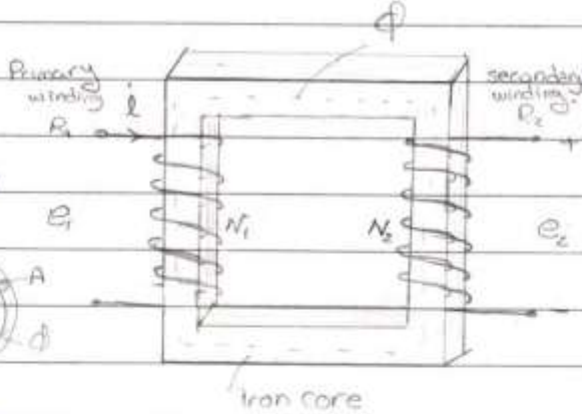
- To convert power from circuit to another at same frequency "primary ct. to secondary ct".
- Transformer is static Device & we use it in AC only.

Transformer

Iron Core

good conductor for magnetic flux

$mmF = Ni$



Cupper core

$\therefore i = \frac{V}{R}$

$R = \frac{\rho L}{A}$

In cupper ρ is small and cheap.

$$\phi = \frac{Ni}{Reluctance}$$

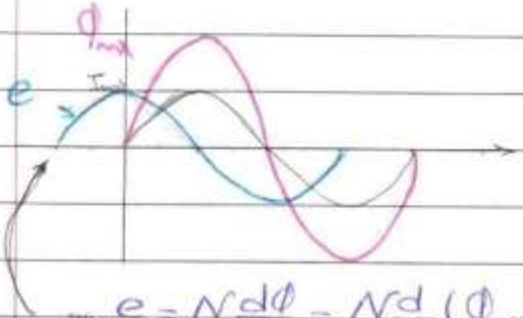
$$R_e = \frac{l}{\mu_0 \mu_r A}$$

μ_r = very high for iron

$\therefore R_e$ is very small

$R_e \downarrow \rightarrow \phi \uparrow\uparrow$

$$\therefore e = N\frac{d\phi}{dt}$$



$i = I_{max} \sin \omega t$

$\phi = \phi_{max} \sin \omega t$

$$\therefore e = N\frac{d\phi}{dt} = N\frac{d}{dt}(\phi_{max} \sin \omega t) = \underbrace{N\phi_{max}\omega}_{e_{max}} \cos \omega t$$

$$e_{max} = N\phi_{max}\omega$$

$$e_{rms} = \frac{N\phi_{max}\omega}{\sqrt{2}}$$

$$e_{rms} = \frac{N \Phi_m \omega}{\sqrt{2}} = \frac{2\pi f N \Phi_{max}}{\sqrt{2}} = \sqrt{2}\,\pi f N \Phi_{max}$$

$$e_{rms} = 4.44 f N \Phi_{max} \quad \#$$

$$E_1 = 4.44 f N_1 \Phi_{max}$$
$$E_2 = 4.44 f N_2 \Phi_{max}$$

$$\frac{E_1}{E_2} = \frac{N_1}{N_2} \quad \#$$

if $N_1 > N_2$ step down Transf.
if $N_1 < N_2$ step up Transf.

$$R_1 = \left(\frac{N_1}{N_2}\right)^2 R_2 \quad \#$$

types of load.

over load	زيادة عن الحد وهذه مش موجود
full load	كل الأجهزة اشتغلت
half load	نص الأجهزة
low load	مفيش اي حاجة شغالة

Ex: 10 K VA , 250/125 V Transf.

sol: $V_{N_1} = 250$

$V_{N_2} = 125$

$10 \times 10^3 = V_1 I_{N_1} = V_2 I_{N_2}$

$= 250 \times I_{N_1} = 125\, I_{N_2}$

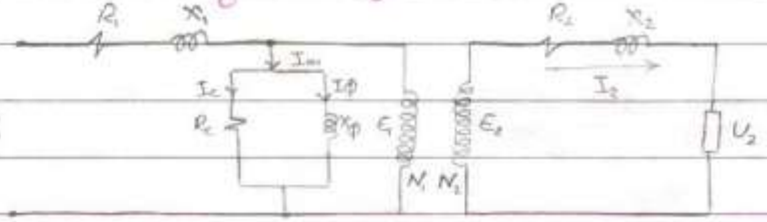
$I_{N_1} = 40\,A$

$I_{N_2} = 80\,A$

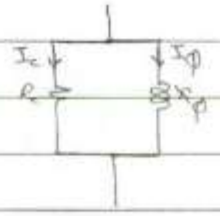
Note: To measure AC $\rightarrow$ RMS

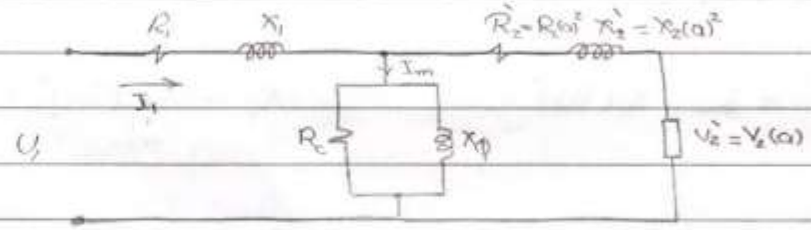
DC $\rightarrow$ average

Equivalent circuit of a transformer.



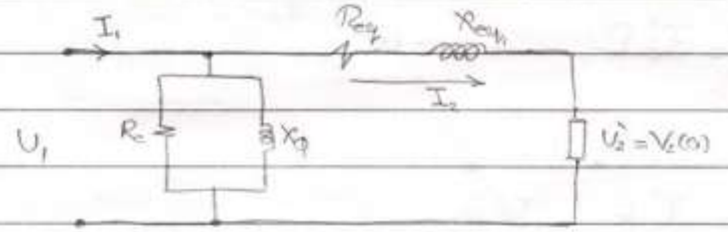
a. Refered to primary side





R_c لا تخضع لقانون ohm.

Exact Eeqivalent Circuit.



Approximate Eeqivalent circuit.

$$R_{eq_{p_1}} = R_1 + R_2^{`} = R_1 + R_2(a)^2$$

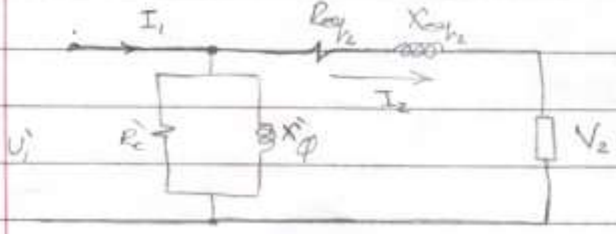
$$X_{eq_{p_1}} = X_1 + X_2^{`} = X_1 + X_2(a)^2$$

$$V_2^{`} = V_2(a)$$

$$I_2^{`} = I_2 \div a$$

where $a = \frac{N_1}{N_2}$

Referred to secondary side



أفضل اشتغل referred
لل Primary ولا secondary
حسب الـ Given [illegible]

$$a = \frac{N_1}{N_2}$$

$$V_1' = V_1 \div a$$

$$R_{eq} = R_2 + R_1' = R_2 + R_1 (1/a)^2 \qquad R_c' = R_{c_1} (1/a)^2$$

$$X_{eq} = X_2 + X_1' = X_2 + X_1 (1/a)^2 \qquad X_\phi' = X_{\phi_1} (1/a)^2$$

Losses.

1- Iron losses

$$P_i = I_c^2 R_c \quad \text{"Fixed"}$$

لأنه [illegible] ثابت

2- Copper losses:

$$P_{cu} = I_1^2 R_1 + I_2^2 R_2$$

$$= I_1^2 R_{eq_1} = I_2^2 R_{eq_2} \;\# \quad \text{"Variable"}$$

$$\text{Total loss} = P_i + P_{cu}$$

Power factor:

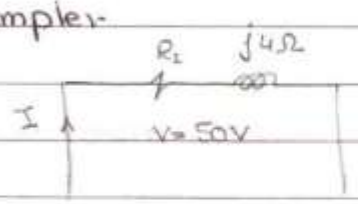
1- unity power factor $Z_L = Z_R$ $\xrightarrow[I]{} V_R$

2- lagging power factor: $Z_L = R + jX_L$

3- leading power factor: $Z_L = R - jX_C$

$$Pf = \cos\phi$$

example:-



Sol:-

$Z_L = 3 + j4 = 5\angle 53.13^\circ$

$I = \frac{V}{Z_1} = \frac{50\angle 0}{5\angle 53.13^\circ} = 10\angle -53.13^\circ$

$P.f. = \cos 53.13 = 0.6$ Lagging

$S = V.I = 50 \times 10 = 500$ VA

$P = V.I\cos\phi = 50 \times 10 \times 0.6 = 300$ W

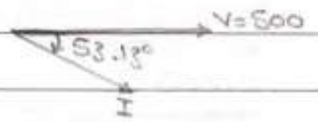
$V.I \sin\phi = 50 \times 10 \times 0.8 = 400$ VAR

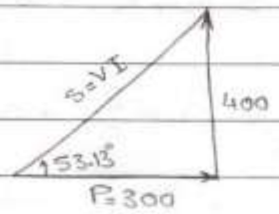
$\cos^2 x + \sin^2 x = 1$

$\sin x = \sqrt{1 - \cos^2 x}$

$= \sqrt{1 - (0.6)^2}$

$= 0.8$





Example:-

A 5KVA, 500/250 V single phase transformer has the following parameter.

$R_1 = 1/2\,\Omega$ & $X_1 = 0.6\,\Omega$ & $R_2 = 0.1\,\Omega$ & $X_2 = 0.15\,\Omega$ &
$R_c = 5\,K\Omega$ & $X_\phi = 500\,\Omega$

Required:-

1) R_{eq_1} & R_{eq_2} 2) cupper losses at full load & Iron losses
3) total losses at half load 4) effeciency at full load & half load at 0.8 Pf. lagging.

sol:-

$$a = \frac{N_1}{N_2} = \frac{500}{250} = 2$$

(1) $R_{eq_1} = R_1 + R_2' = 1/2 + (0.1)(2)^2 = 0.9\,\Omega$

$X_{eq_1} = X_1 + X_2' = 0.6 + (0.15)(2)^2 = 1.2\,\Omega$

$$R_{eq_2} = R_2 + \frac{R_1}{a^2} = 0.1 + \frac{0.5}{4} = 0.225\,\Omega$$

$$X_{eq_2} = X_2 + \frac{X_1}{a^2} = 0.15 + \frac{0.6}{4} = 0.3\,\Omega$$

N.B $R_{eq_1} = R_{eq_2}(a)^2$

(2)

$5\,KVA = 5000 = 500\,I_{N_1} = 250\,I_{N_2}$

$I_{N_1} = 10\,A$

$I_{N_2} = 20\,A$

$P_{cu}|_{full} = I_N^2 R_1 + I_N^2 R_2 = (10)^2(0.5) + (20)^2(0.1) = 50 + 40 = 90\,W$

or

$P_{cu}|_{full} = I_{N_2}^2 R_{eq_2} = (20)^2(0.225) = 90\,W$

$P_{\substack{half\\load}} = P_{\substack{full\\load}}\,(\overset{(1/2)^2}{1/4}) = 22.5\,W$

$P_i = I_c^2 R_c$

where $I_c = \dfrac{V}{R_c} = \dfrac{500}{5000} = 0.1\,A$

$P_{iron} = (0.1)^2 \times 5000 = 50$ watt

$- \text{loss}\big|_{\text{at full load}} = P_i + P_{cu} = 50 + 90 = 140\ w$

at 50% load

$\text{loss} = 50 + 22.5 = 72.5\ w$ — ال loss الخاصة بال iron ثابتة في كل أحوالها

$$\eta = \frac{P_{out} \cdot pf}{P_{out} \cdot pf + \text{losses}}$$

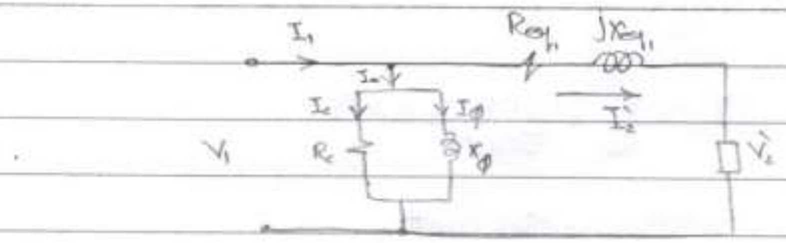
$$\eta_{F.L} = \frac{5000 \times 0.8}{5000 \times 0.8 + 50 + 90} = 0.966\ \% = 96.6\ \%$$

$$\eta_{HL} = \frac{\frac{1}{2}(5000)(0.8)}{\frac{1}{2}(5000)(0.8) + 50 + 90(0.5)^2} = \frac{2000}{2072.5} = 96.5\ \%$$

$$\eta_{x\cdot load} = \frac{x\,(KVA)(P.f)}{x\,(KVA)(P.f) + P_{iron} + P_{cu_{\text{full load}}}\,(x^2)}$$

$0 < x < 1$

$$X_m = \sqrt{\frac{P_i}{P_{cu_{Full}}}}$$ ← ماهي ال X_m ؟؟



عايزين نجيب بقى الـ Parameter اللى هى R_c & X_ϕ و R_{eq}

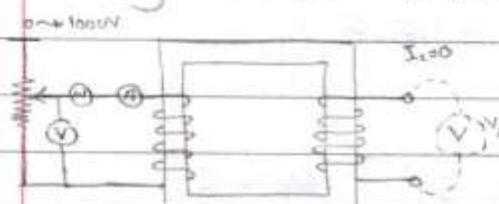
Parameters

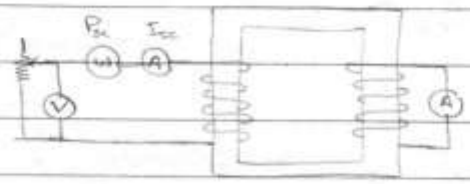
Iron part	Cupper part
$R_c + X_\phi$	$R_{eq} + X_{eq}$
open circuit test	short circuit test
O.C.T	S.C.T

← تجارب بالتالي أجيب → قيم الثوابت

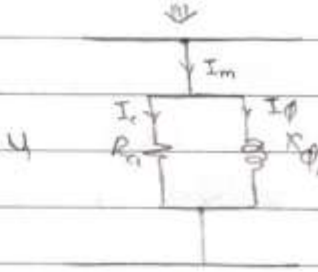
(HVS) high voltage side → Primary يعني عند

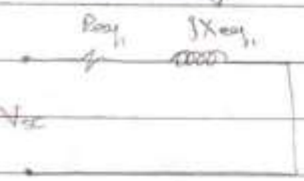
Secondary يعني مفتوح أي لا ملامس في الـ





V_o	I_o	P_o	V_2
[illegible]			50
[illegible]			
[illegible]			250



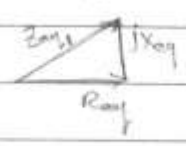


$$P_{sc} = I_{sc}^2 R_{eq_1}$$

$$R_{eq_1} = \checkmark$$

$$V_{sc} = I_{sc} Z_{eq_1}$$

$$X_{eq_1} = \sqrt{Z_{eq_1}^2 - R_{eq_1}^2}$$



يعني نسبة sec

open أو voltmeter

لا ما يقول (HVS) يقول لأن المقاومة الداخلية

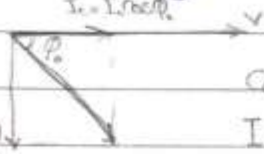
العريض تكون ∞

O.C.T (HVS):

500V, 1A, 120W

Power transformer

secondary is open



$\therefore P_o = V I_o \cos\phi$

$\cos\phi_o = \checkmark$ $I_c = \checkmark$

$I_\phi = \checkmark$

ها أهمل الدائرة بتاعة الـ iron لأن كان الـ 500V Volt
كان هاتي تيار 1A وفي التجربة دي الجهد هيكون 50V
يبقى التيار 0.1A فممكن أهمل الدائرة

يفضل اشتغل الـ O.C.T عند الـ Primary لأنه بكدة أنا هجيب أرفع الجهد لحد 250 بدل 500 وبكدة التيار عند الـ Primary صغير فبكدا يفضل يكون عند الـ sec.

Example:- 10 KVA, 500/250 V, single phase transformer has a following test data:-

open circit test (O.C.T) (H.V.S) , 500 V, 1A, 200 watt

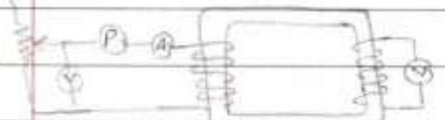
short circuit test (S.C.T)(L.V.S) , 25V , 40 A , 600 watt

(1) Obtain the parameter of this transformer refered to primary & refered to secondary side.

(2) Obtain the max. effeciency at 0.8 P.f. lagging.

Sol:-

(1) O.C.T (HVS) — 500V, 1A, 200 watt



$P_o = V_o I_o \cos\phi$

$\cos\phi = \frac{200}{(500)(1)} = 0.4$

$\sin\phi = 0.96$

$I_c = I_o \cos\phi = 0.4A$

$I_\phi = I_o \sin\phi = 0.96A$

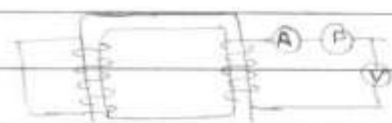
$R_{c_1} = \frac{V_o}{I_c} = \frac{500}{0.4} = 1250\,\Omega$

$X_{\phi_1} = \frac{V_o}{I_\phi} = \frac{500}{0.96} = 545.5\,\Omega$

$R_{c_2} = \frac{R_{c_1}}{a^2} = \frac{1250}{4} = 312.4\,\Omega$

$X_{\phi_2} = \frac{X_{\phi_1}}{a^2} = \frac{545.5}{4} = 136.4\,\Omega$

S.C.T (L.V.S) — 25V, 40A, 600 watt



$P_{sc} = I_{sc}^2 R_{eq_{r_2}} \rightarrow$

$R_{eq_{r_2}} = \frac{600}{(40)^2} = 0.375\,\Omega$

$V_{sc} = I_{sc} Z \rightarrow$

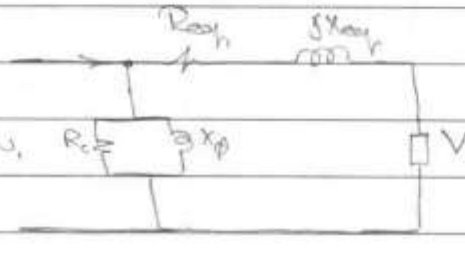
$Z = \frac{V_{sc}}{I_{sc}} = \frac{25}{40} = 0.625\,\Omega$

$X_{eq_{r_2}} = \sqrt{Z^2 - R_{eq_{r_2}}^2} = 0.5\,\Omega$

$R_{eq_h} = R_{eq_{l_2}}(a)^2 = 4 * 0.375$ #

$= 1.5\,\Omega$

$X_{eq_h} = X_{eq_h} a^2 = 2\,\Omega$ #



لا جب يقول H.V.S أو L.V.S دقيقة شانه أعرف انه ال R وال X اللي طالع
فتكون referred لأن نحن لو H.V.S بيعطي ال X وال R بتكون referred لل Primary
L.V.S ← يعني فتكون referred to secondary

(b)

$P_{in} = 200\,W$ "open ct."

or $I_c^2 R_c = 200\,W$

$$P_{cu(FL)} = I_{N_1}^2 R_{eq_{r_1}} = I_{N_2}^2 R_{eq_{r_2}}$$
$$= (20)^2(1.5) = (40)^2(0.375) = 600\,W$$

من هنا نطلع الـ Power نتيجة الـ (Cu_{FL}) تعويض من نتيجة الـ Short ct. test.

Voltage Regulation : The change in the secondary voltage from no load to full load for the same primary voltage

* The voltage regulation is like the figure of merit of a transformer.

Ideal transformer V.R = zero.

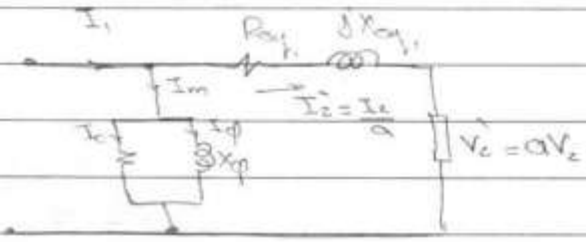
$E_2 = I_2 Z_2 + V_2$

$$\frac{E_1}{E_2} = \frac{N_1}{N_2} = a$$

$$* \; V.R = \frac{V_1 - V_1'}{V_2} = \frac{580 - 500}{500} = \frac{80}{500} = 16\%$$

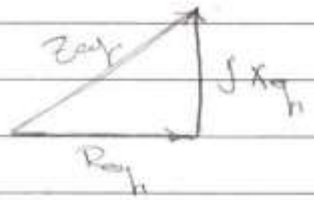
$V.R = V_1 - V_2$

$$V.R\% = \frac{V_1 - V_2'}{V_2} \times 100 =$$



$$I_1 = I_2 \angle \pm\phi_2 + \frac{V_1}{R_c} - j\frac{V_1}{X_\phi}$$

$$= a \pm jb = \sqrt{a^2+b^2} \angle \pm \tan^{-1}\frac{b}{a}$$



$$V_1 = V_2' \angle 0 + I_2' \angle \pm\phi_2 \; Z_{eq_{1}} \angle \theta$$

$$= A + jB$$

$$V_1 = \sqrt{A^2+B^2} \angle \tan^{-1} B/A = \phi_1$$

where $|Z_{q_1}| = \sqrt{R_{eq_1}^2 + X_\phi^2} \angle \tan^{-1} X_{eq_1}/R_{eq_1}$

$P_{in} = V_1' I_1 \cos\phi_1$

where $\phi_1 = \alpha + \beta$

$P_{out} = V_2 + I_2 \cos\phi_2$

ex8-

Example: 10 KVA, 500/250 V, single phase transformer has the following parameter.

$R_1 = 1.2\,\Omega$, $X_1 = 1.6\,\Omega$ $\quad$ $R_c = 1200\,\Omega$

$R_2 = 0.3\,\Omega$, $X_2 = 0.4\,\Omega$ $\quad$ $X_\phi = 500\,\Omega$

Required:-

(V_1) 1- Obtain the supply voltage ~~at~~ full load and 0.8 p.f lagging

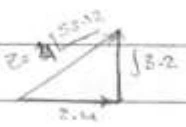
(I_1) 2. obtain the input current at this case.

($\frac{V_1 - V_2'}{V_2'}$) 3. obtain the voltage regulation.

sol:-

$R_{eq_1} = 1.2 + 0.3(2)^2 = 2.4\,\Omega$

$X_{eq_1} = 1.6 + (0.4)(4) = 3.2\,\Omega$



$V_1 = V_2' \angle 0 + I_2' \angle \phi \; Z \angle \theta$

$(250)(a) \rightarrow$ $= 500 \angle 0 + (20 \angle -36.87)(4 \angle 53.13)$

$= 500 \angle 0 + 80 \angle 16.26$

$= 500 + 80 [0.96 + j0.28]$

$= 500 + 76.8 + j22.4$

$= 576.8 + j22.4 = 577.23 \angle 2.22$

$V.R = V_1 - V_2' = 77.23\,V = \frac{77.23}{500} * 100 = 15.44\,\%$

$I_1 = I_2' + I_c + I_\phi$

$= 20 \angle -36.87 + \frac{577.23}{1200} - j \frac{577.23}{500}$

$= 16 - j12 + 0.48 - j1.75$

$\simeq 16.48 - j13.15 = 21.08 \angle -38.58$

$P_1 = V_1 I_1 \cos\phi = 577.23 * 21.08 * \cos(38.58 + 2.22) \rightarrow 0.8$

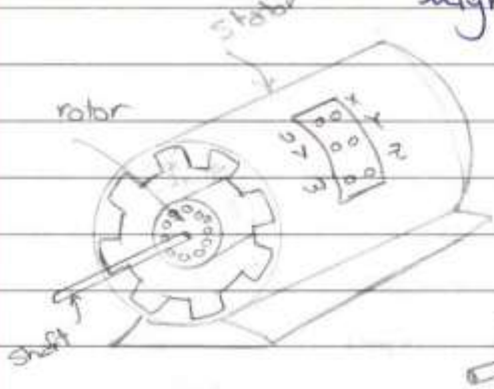
$= 9211.1\,W$

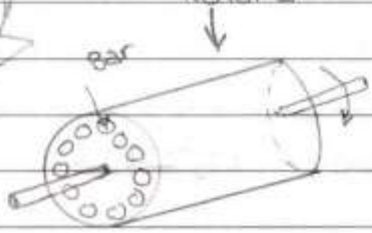
$P_{out} = V_2 I_2 \cos\phi = 250 * 40 * 0.8 = 8000$ watt

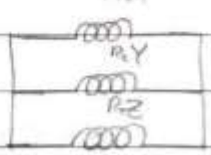
Chapter II
Three phase Induction Motors.

Stator + Rotor

(wound Rotor) high power | (squirrel cage Rotor) low power

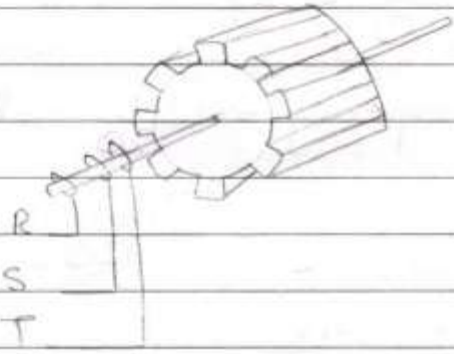




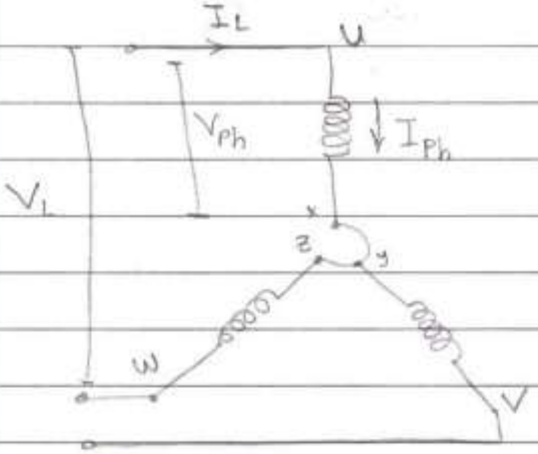


secondary

يحمل تيار كبير
squirrel cage



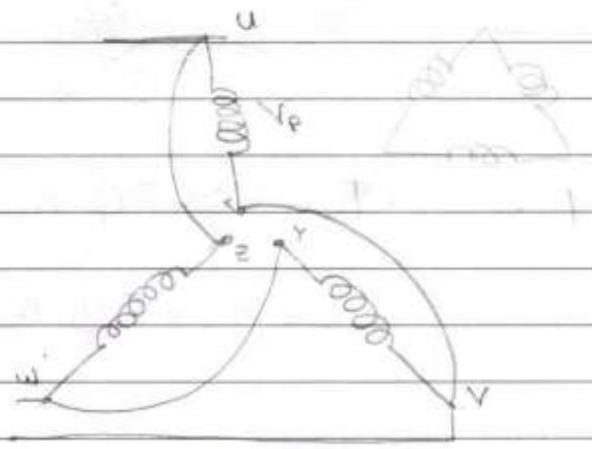
Star



$V_L = \sqrt{3}\, V_{Ph}$

$I_L = I_{Ph}$

Delta



$V_L = V_{Ph}$

$I_L = \sqrt{3}\, I_{Ph}$

Let slot $(S) = 12$

Poles $(P) = 2$

Phases $(m) = 3$

* n_s : Synchronous speed $= \frac{120f}{P}$ rpm

$= \frac{120 * 50}{2} = 3000$ rpm

$emf = N \frac{d\phi}{dt}$

$F = Bli$

* slip speed $= n_s - n_r$ rpm

* $S = \frac{n_s - n_r}{n_s} \qquad 0 \leq S \leq 1$

at starting $S = 1$ and $n_r = 0$

* stator frequency $= \frac{P n_s}{120} = f_1$

* Rotor frequency $= \frac{P(n_s - n_r)}{120} = f_2$

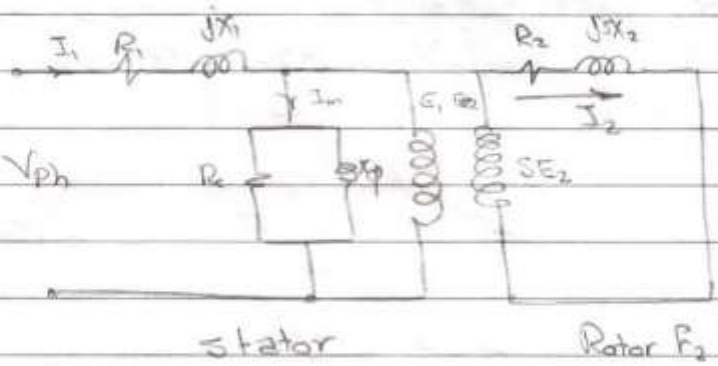
$\therefore f_2 = \frac{P(n_s - n_r)}{120} \times \frac{n_s}{n_s} = \frac{P n_s}{120} \cdot \frac{n_s - n_r}{n_s}$

$f_2 = f_1 S$ *

$E_1 = 4.44 f_1 \phi N_{ph}$

$E_2 = 4.44 f_2 \phi N_{ph} \simeq S E_{20}$

Equivalent Circuit



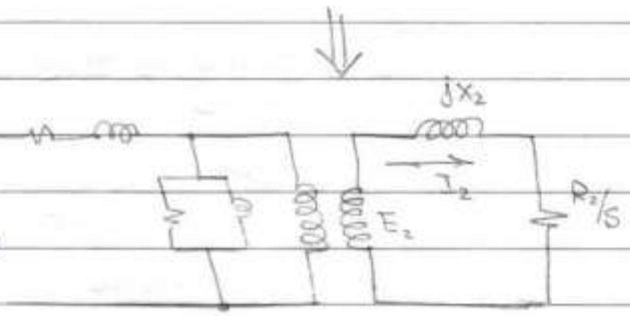
$$I_2 = \frac{SE_2}{R_2 + jSX_2}$$

$$= \frac{E_2}{\frac{R_2}{S} + jX_2}$$

$$\frac{R_2}{S} = R_2 + \frac{R_2}{S}(1-S)$$

$$= R_2 + R_m$$

R_m: resistance due to load.

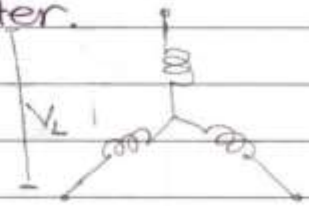


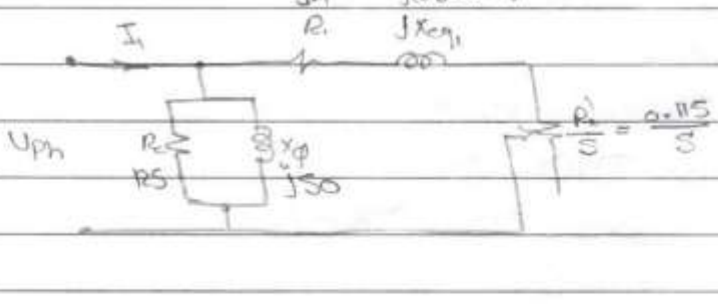
Examples–

A 433V star connection four Pole 50Hz, 1425 rpm (full load) Three phase induction motor has the following Parameter $R_1 = 0.1\Omega$, $X_1 = 0.3\Omega$, $R_2' = 0.115$, $X_2' = 0.4\Omega$, $R_c = 125\Omega$, $X_\varphi = 50\Omega$, obtain

1- The slip at full load
2- The input (stator) Current and input power factor.
3- The full load efficiency if the fractional losses = 2.3
4- The starting Torque in newton meter.

حل المسألة دي في شرح الأول وبعد كده حل المسألة.





* لو ما اداليش ال R_c في أو أنه اعطاها ب ∞

* دايماً ال volt اللي بيدهولي هو V_L ولو قال delta هيبقى الـ ph هو هو

$$V_{ph} = \frac{V_L}{\sqrt{3}} = \frac{433}{\sqrt{3}} = 250\,V$$

$$n_r = 1425 \text{ rpm}$$

$$n_s = \frac{120f}{P} = \frac{120 * 50}{4} = 1500 \text{ rpm}$$

(a) $$S_{F.L} = \frac{n_s - n_r}{n_s} = \frac{1500 - 1425}{1500} = 0.05 \text{ P.u} = 5\%$$

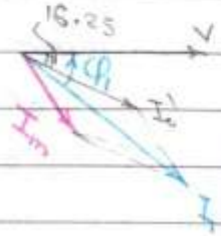
$$\frac{R_2'}{S} = \frac{0.115}{0.05} = 2.3\,\Omega$$

(b) $$I_2' = \frac{V_{ph}}{(0.1 + 2.3) + j0.7} = \frac{250\angle 0}{2.4 + j0.7} = \frac{250\angle 0}{2.2\angle 16.26}$$

$$= 100\angle -16.26\ A = 96 - j28$$

$$I_m = I_c + I_\phi = \frac{250}{125} - j\frac{250}{50} = 2 - j5$$

$$I_1 = I_m + I_2' = 98 - j33 = 103.4\angle -18.6\ A$$



دايماً ال Pf بالكوس زاوية I_1

$$P.f = \cos\varphi_1 = \cos 18.6 = 0.9477 \text{ lagging}$$

(c)

$$\overbrace{P_{cu} + P_{core} \qquad P_g = 3I_2'^2\frac{R_2'}{S}}^{P_{in}}$$

$$\overbrace{P_{cu_2} \qquad P_m}^{P_g}$$

$$\overbrace{P_f \qquad P_{out}}^{P_m}$$

$$P_{in} = 3(250)(103.4)(0.9477)$$
$$= 73495\ \omega$$

$$P_g = 3I_2'^2\frac{R_2'}{S} = 3(100)^2(2.3) = 69000\,\omega$$

$$P_m = P_g(1-S) = 69000 * 0.95$$
$$= 65550\ \omega$$

$$P_{out} = P_m - P_f = 65550 - 2300$$
$$= 63250\ \omega$$

$$P_{out}\Big|_{hp} = \frac{63250}{746} = 84.7 \text{ hp}$$

تحويله من ال W الى hp و 746 ثابت

$$\eta = \frac{63250}{73495} = 86\ \%$$

(d)

$$T_{f.L} = \frac{P_{af}}{\omega_s} = \frac{69000}{2\pi \times \frac{1500}{60}}$$

علشان أجيب ال Torque عوضنا بال S في الحالة اللي عايزها.

$$= \frac{69000}{50\pi} = 439.5 \text{ N.m}$$

→ Starting torque at S = 1 ⇒ T_{st} starting torq.

$$I_2' = \frac{250}{\underbrace{(0.215 + j0.7)}_{(0.112+0.1)}} = 341.4$$

التيار عند ال start كبير

$$P_g = 3(341.4)^2\ 0.115 = 40212 \text{ W}$$

$$T_{st} = \frac{P_{g\,st}}{\omega_s} = \frac{40212}{50\pi} = 256 \text{ N.m}$$

ratio of T_{st} to T_{FL} $= \frac{256}{439.5} = 0.58 = 58\ \%$

بسم الله قبل الـ أكله

$$n_s = \frac{120f}{P} \quad rpm$$

$$S = \frac{n_s - n_r}{n_s} \quad pu \text{ 'Per unit'}$$ دايماً الـ $n_s > n_r$

* at starting ($n_r = 0$) $\Rightarrow S = 1$
* at noload $n_r \to n_s \Rightarrow S \to 0 \Rightarrow 0 < S < 1$

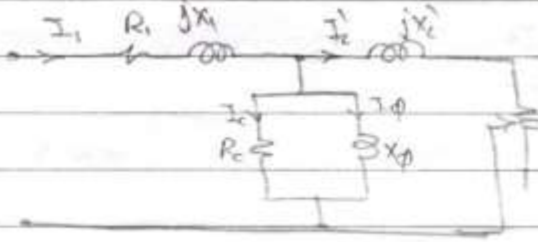
$$S_{FL} = [0.03 \to 0.06]$$

$\therefore \frac{R_2}{S} > R_2$ لأن الـ S رقم أقل من 1

$$\frac{R_2}{S} = R_2 + R_m$$

or $$\frac{R_2}{S} = R_2 + \frac{R_2(1-S)}{S}$$

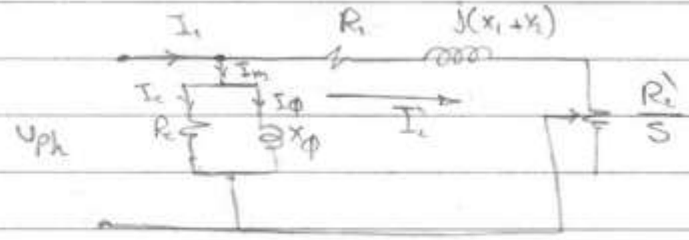
علشان دي كدة لأن انا اصلاً عندي R_2 دايماً ثابتة والـ load بيتغير فبيغير R_m



$$\frac{R_2'}{S} = R_2 + \frac{R_2(1-S)}{S}$$

Exact E. Circuit

* → Approximate Elec. circuit



$$I_m = I_c + I_\phi = \frac{V_{ph}}{R_c} - j\frac{V_{ph}}{X_\phi}$$

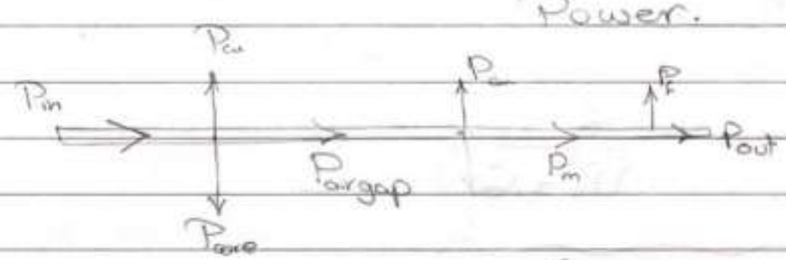
$$I_2' = \frac{V_{ph}\angle 0}{(R_1 + \frac{R_2'}{S}) + jX_{eq_r}} = \frac{V_{ph}\angle 0}{\sqrt{(R_1 + \frac{R_2'}{S})^2 + X_{eq_r}^2}} \angle -\tan^{-1} X_{eq}/R_1 + R_2'/S$$

$$I_1 = I_m + I_2' = |I_1| \angle -\phi_1$$

$$P_{in} = 3\, V_{ph}\, I_1 \cos\phi_1$$

3phase لانه

* توزيع ال Power.



three phase

$$P_{in} = 3\, V_{ph}\, I_1 \cos\phi_1$$

stator losses

$P_{cu} = 3 I_1^2 R_1$

$+ \; P_{core} = 3 I_c^2 R_c$

Air gap power

$P_g = T_d \omega_s$

$= 3 I_2'^2 \frac{R_2'}{S}$

$P_{core} = 3 I_2'^2 R_2'$

$= S P_g$

$P_m = 3 I_2'^2 R_m$

$= P_g (1 - S)$

Note: losses of iron in rotor is very small

P_{fr}

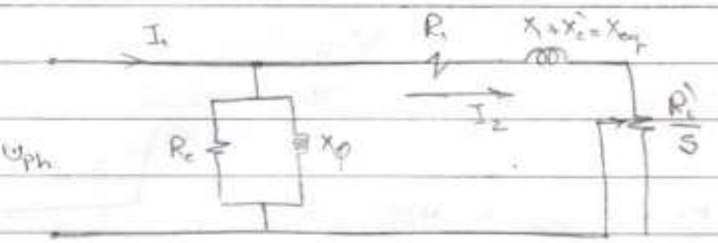
Given

P_{out}

$= T_{sh} \omega$

$\omega_m = \frac{2\pi n_r}{60}$ ** $P_{elec} = V.I$

$\omega_s = \frac{2\pi n_s}{60}$ * $P_{Mech} = T.\omega$



$$\therefore T_d = \frac{P_g}{\omega_s} = \frac{3 I_2'^2 R_2'/S}{\omega_s} = \frac{3 R_2'}{\omega_s S} I_2'^2$$

$$= \frac{3 R_2'}{\omega_s S} \frac{V_{ph}^2}{\left(R_1 + \frac{R_2'}{S}\right)^2 + X_{eq}^2}$$

To Get Max. S

$$\frac{dT_d}{dS} = 0$$

$$\boxed{\therefore S_{Max} = \frac{R_2'}{\sqrt{R_1^2 + X_{eq}^2}}}$$ #

حفظ

$$T_{max} = \frac{3 V_{ph}^2}{3 \omega_s \left[R_1 + \sqrt{R_1^2 + X_{eq}^2} \right]}$$

لا يتوقف على R_2

* assume $R_1 = 0$ "stator"

$$\therefore T_d = \frac{3}{\omega_s} \frac{V_{ph}^2}{\left(\frac{R_2'}{S}\right)^2 + X_{eq}^2} \frac{R_2'}{S} = KS$$

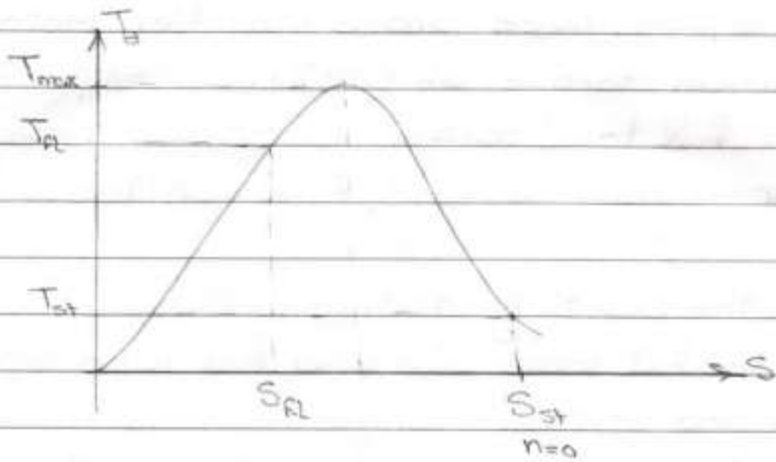
$$S_{max} = \frac{R_2'}{X_{eq}}$$ #

$$T_{max} = \frac{3 V_{ph}^2}{2 \omega_s X_{eq}}$$ #

$$\frac{T}{T_{max}} = \frac{2 \frac{R_2'}{S} X_{eq}}{\left(\frac{R_2'}{S}\right)^2 + (X_{eq})^2} = \frac{2}{\frac{R_2'}{S X_{eq}} + \frac{S X_{eq}}{R_2'}} = \frac{2}{\frac{S_{max}}{S} + \frac{S}{S_{max}}}$$

$$\boxed{T_{F.L} = \frac{2 T_{max}}{\frac{S_{max}}{S_{F.L}} + \frac{S_{F.L}}{S_{max}}}}$$

Given T_{max}, S_{max}



(T/S Curve)

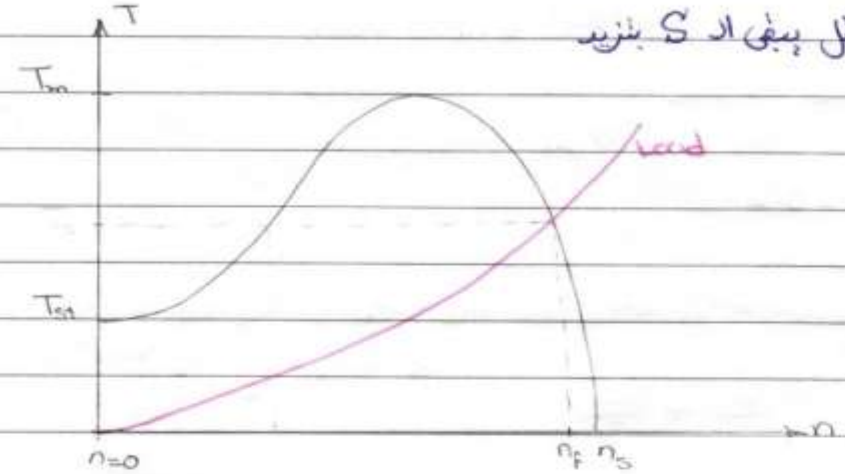
$$S = \frac{n_s - n}{n_s}$$

$$S n_s = n_s - n$$

$$n = n_s - S n_s$$

$$n = n_s(1 - S)$$

كل لما الـ n بتقل بيبقى الـ S بتزيد



s=1 (T/n curve) s=0

اتجاه زيادة الـ S

Example :-

A 50HZ, 6 pole, three phase induction Motor has a maximum torque of 200% at a slip of 0.2 if the full load torque is 50 N.m. neglect the stator resistance and fraction losses

1. Obtain the starting torque in N.m
2. Obtain the full load slip and full load speed
3. The speed at Max. torque
4. Obtain the added resistance to the rotor to obtain the max torque at starting at the sam torque
5. Obtain the Radd to change the speed at full load to 900 R.P.M

Sol :

[illegible]

$$n_s = \frac{120F}{P} = \frac{120(50)}{6} = 1000 \text{ rpm}$$

$T_{max} = 200\% = 2 \text{ pu}$

$S_{max} = 0.2$

$T_{F.l} = 50 \text{ N.m}$

(a) $$T_s = \frac{2\,T_{max}}{\frac{S}{S_{max}} + \frac{S_{max}}{S}}$$ at starting $S=1$

$$T_s = \frac{2(2)}{\frac{1}{0.2} + \frac{0.2}{1}} = \frac{4}{5.2} = 0.77 \text{ Pu}$$

(b) Full load at S_F

$$T_{F.L} = \frac{2\,T_{max}}{\frac{S_F}{S_{max}} + \frac{S_{max}}{S_F}}$$

لأن عارف ان الـ Torque عند الـ full load بيساوي 1 Pu

$$1 = \frac{2(2)}{\frac{S_F}{0.2} + \frac{0.2}{S_F}} \Rightarrow \frac{S_F}{0.2} + \frac{0.2}{S_F} = 4$$

$S_f^2 + 0.04 = 0.8 S_f$

$S_f^2 - 0.8 S_f + 0.04 = 0$

$S_f = 0.746$ $\quad$ $S_f = 0.053$

refused $\quad$ Accept $\quad$ لازم ال S_f تكون أقل من S_{max}

$S_{max} > S_f$

$\therefore S_f = 0.053$ P.u $= 5.3\ \%$

$n_f = n_s(1 - S_f) = 1000(1 - 0.05)$
$= 950$ rpm

(b) $n_{max} = n_s(1 - S_m)$
$= 1000(1 - 0.2) = 800$ rpm.

$$R_{add} = \frac{S_2 - S_1}{S_1} R_2$$

key

(d) to obtain max. torque (S_1) at the start of the same torque (S_2)

$\therefore S_1 = S_{max}$

$S_2 = S_{st} = 1$

$\therefore R_{add} = \frac{1 - 0.2}{0.2} * R_2 = 4 R_2$

(e) to change speed at full load to 900 rpm

$\therefore S = \frac{n_s - n_r}{n_s}$

$S_{f.L} = 0.053$ calculated in (b) $\quad$ $S|_{900} = \frac{n_s - 900}{n_s}$

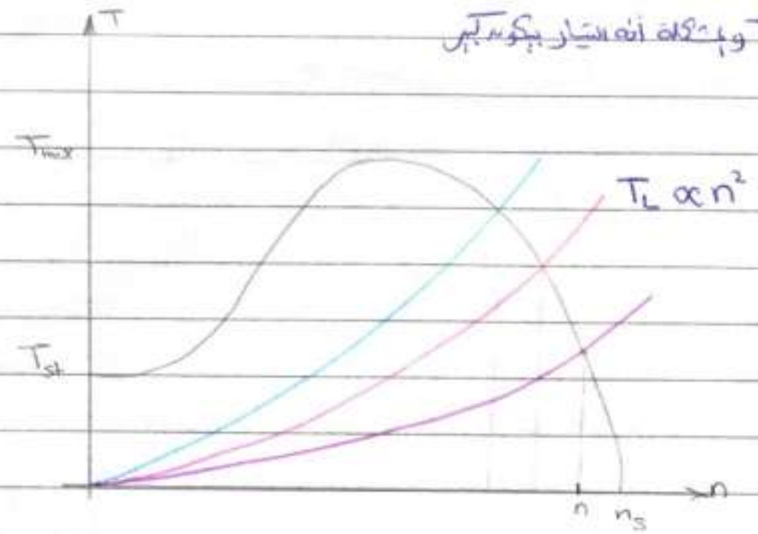
$S|_{900} = \frac{1000 - 900}{1000} = 0.1$

$\therefore R_{add} = \frac{0.1 - 0.053}{0.053} R_2 = 0.88 R_2$

$\simeq R_2$

Note :-

يهمني في أي Motor إن أكبر
الـ T_{st} ومشكلة انه التيار بيكون كبير

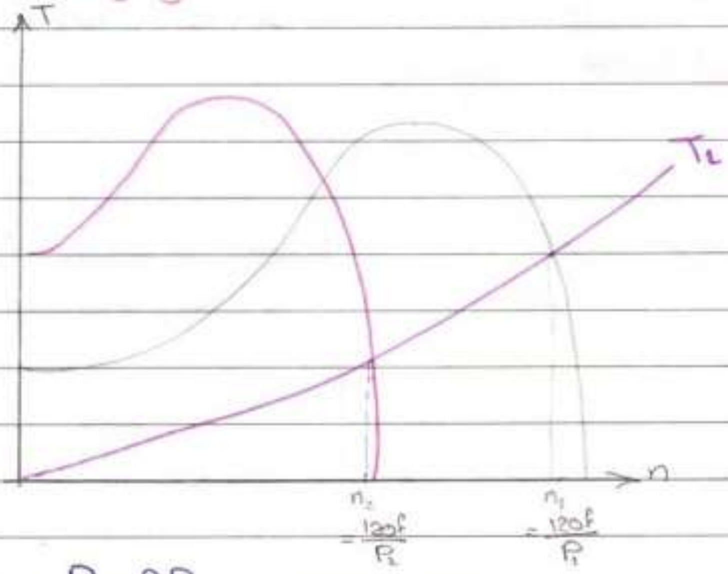


كل لما أزود الحمل بسرعة تقل

* Speed control of induction Motor

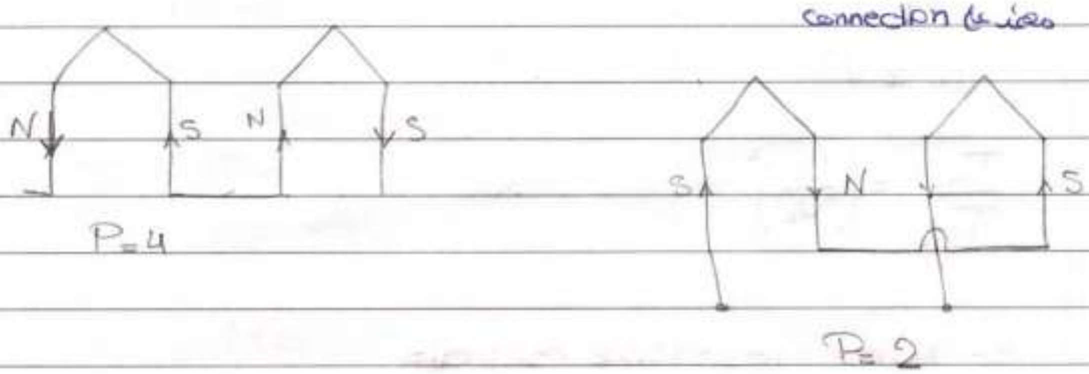
1- Pole changing "squirrel case" مع النوعين بس
2- Line frequency control
3- line Voltage control
4- Rotor resistance control "wound Rotor" في النوعية

1- Pole changing



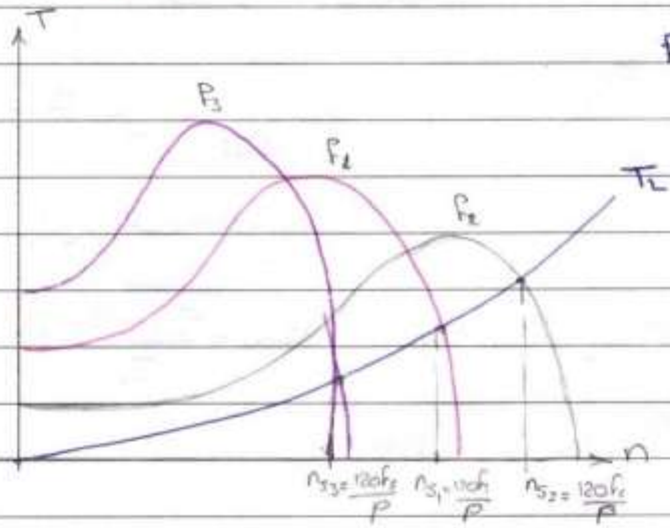
where $P_2 = 2P_1$

تغير الاقطاب بيكون
connection معين



2- frequency control افضل طريقه مستخدمة حاليا

$f_2 > f_1 > f_3$



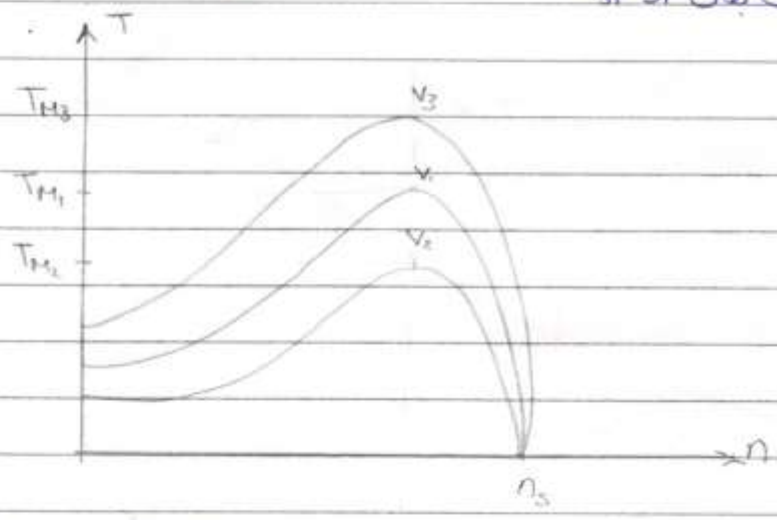
$\therefore T_{max} = \frac{3V_{ph}^2}{2\omega_s X_{eq}} \alpha \left(\frac{V}{f}\right.$

$T_M \alpha 1/f^2$

$\frac{T_{M_1}}{T_{M_2}} = \left(\frac{f_2}{f_1}\right)^2$

3 line voltage control

مستخدمة أكثر في ال DC
مشكلته إني بقلل ال T_{st}

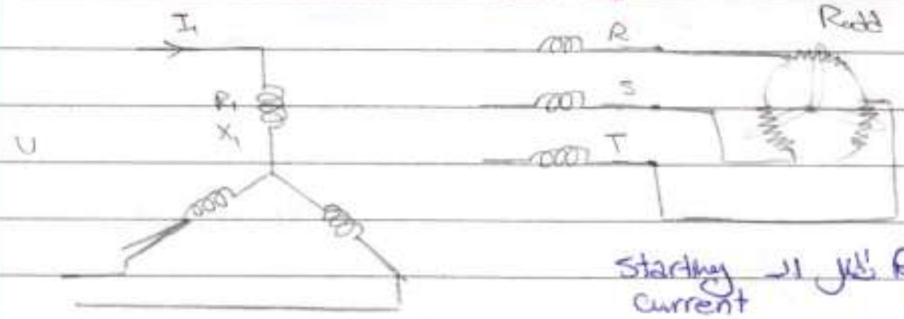


$V_3 > V_1 > V_2$

$T_m \propto V^2$

$$\frac{T_{M_1}}{T_{M_2}} = \left(\frac{V_1}{V_2}\right)^2$$

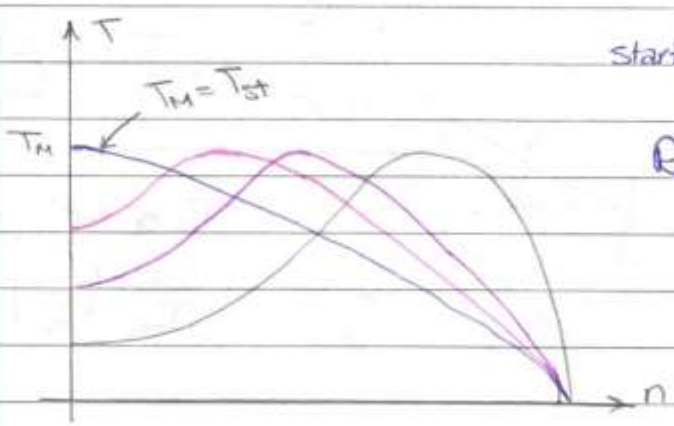
4- Rotor resistance controlle



Radd تقلل ال starting current

وتزود ال starting torque

$$R_{add} = \frac{S_2 - S_1}{S_1} \cdot R_2$$



P_o

A 50 hpower, 3 phase, 440 V, 4 pole, 60 HZ wonded rotor induction motor developed its rated torque at a speed of 1746 rpm. The max Torque is 200% and the rotor resistance = 0.1 Ω, neglect rotitional losses and the stator resistance.

Cal. 1- The slip at Max torque & the speed.

2- The starting torque in N.m

3- R_{add} to produce a Max Torque at starting.

Sol: $P = 4$ $f = 120$

$$n_s = \frac{120f}{P} = \frac{120(60)}{4} = 1800 \text{ rpm}$$

$n_f = 1746$ rpm

$$S_f = \frac{n_s - n_f}{n_s} = \frac{1800 - 1746}{1800} = 0.03 \text{ Pu} = 3\%$$

(a) $$T_f = \frac{2T_{max}}{\frac{S_{max}}{S_f} + \frac{S_f}{S_{max}}}$$ $\because T_{max} = 200\% = 2$ Pu

$$1 = \frac{2(2)}{\frac{S_{max}}{0.03} + \frac{0.03}{S_{max}}}$$

$$\frac{S_{max}}{0.03} + \frac{0.03}{S_{max}} = 4$$

$$S_{max}^2 + 9 \times 10^{-4} = 0.12 S_{max}$$

$$S_{max}^2 - 0.12 S_{max} + 9 \times 10^{-4} = 0$$

$S_{max} = 0.112$ $S_{max} = 0.008$

Accept refused

becaus S_{max} must greater than $S_{f.l}$

$$n_{max} = n_s(1 - S) = 1800(1 - 0.112)$$
$$= 1598.4 \text{ rpm}$$

(b) $$T_{st} = \frac{2\,T_{max}}{\frac{S_{max}}{S_{st}} + \frac{S_{st}}{S_{max}}}$$

$$= \frac{4}{\frac{0.112}{1} + \frac{1}{0.112}} = 0.4425\,P_u$$

بس هو طالبها بـ N.m
[illegible] فلازم اجيب
[illegible] refference
قيمة ال torque [illegible] بعدين
بال N.m
القيمة refer هو ال Td

at $P_f = 0$ ∴

∴ $P_m = P_o + P_f$

∴ $P_m = P_o = 50$ hp

$= 50 * 746 = 37800$ N.m

∴ $P_o = T_d\,\omega$

∴ $\omega = \frac{2\pi\ 1746}{60} = 182.84$

$$T_d = \frac{P_o}{\omega} = \frac{37300}{182.84} = 204 \text{ N.m}$$

∴ $T_M = 2\,T_d = 408$ N.m   ($2P_u$)

$T_{st} = 0.4425\,(204) = 90.27$ N.m

(3) R_{add} to produce Max torque at St. to
(S_1) S_2

$$R_{add} = \frac{S_2 - S_1}{S_1} R_2 = \frac{1 - 0.112}{0.112}(0.1) = 0.793$$

http://www.com-dep.tk/